Tutorial: LWR Decay Heat Analysis with SCALE

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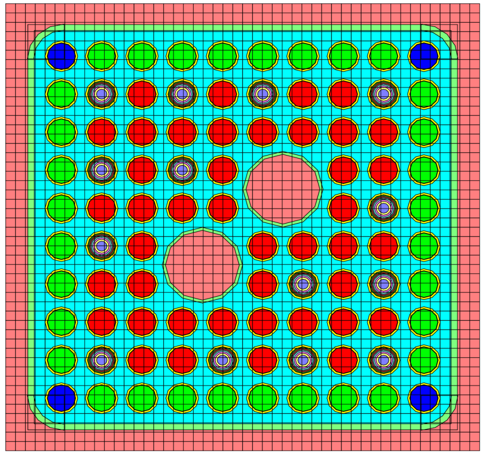
Learning goals

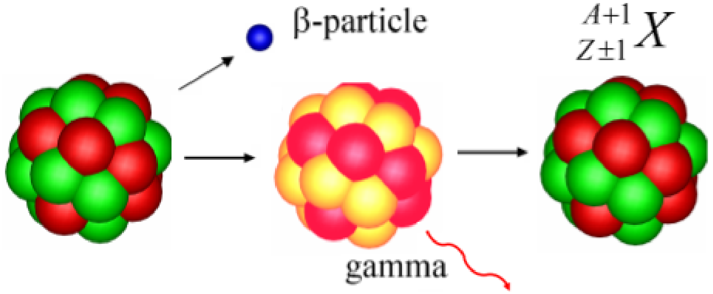
- How to calculate decay heat in LWR spent fuel assemblies using capabilities and nuclear data libraries in SCALE 6.2.4
- How to apply different approaches for decay heat calculation for a typical LWR assembly

scale
Nuclear Systems Modeling & Simulation

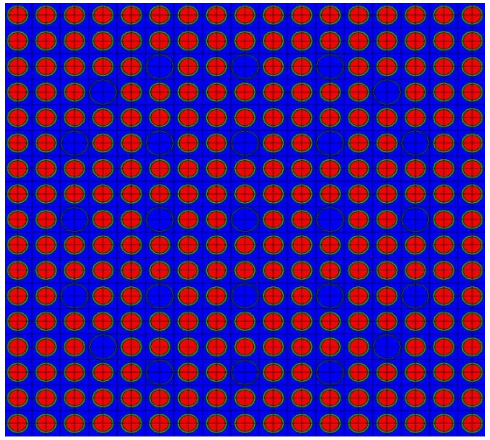
What is residual decay heat?



- Decay heat generated in spent nuclear fuel = recoverable energy released from the decay of radionuclides in fuel after its discharge from the reactor

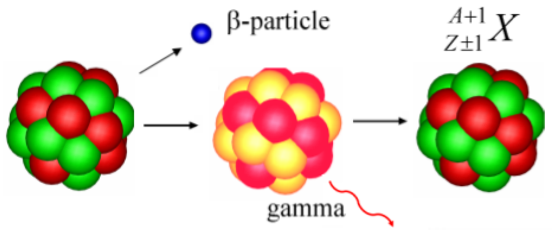


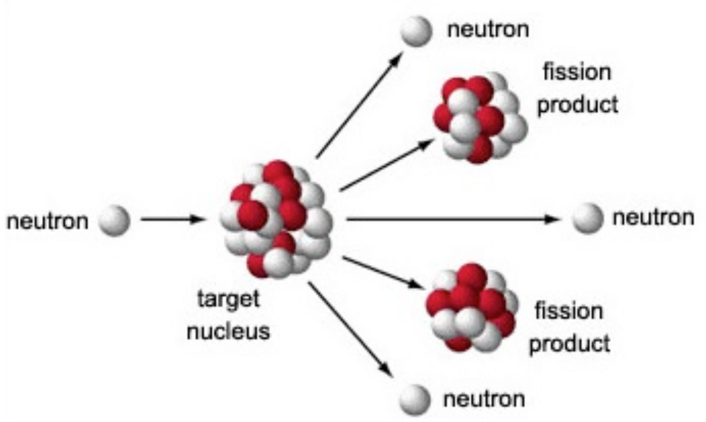
- Decay heat is driven by the nuclide composition in fuel at the end of irradiation
- Calculation of decay heat can be performed with computational tools that simulate
  - nuclide transmutations and decay processes during fuel irradiation in the reactor
  - decay from discharge to a designated cooling time

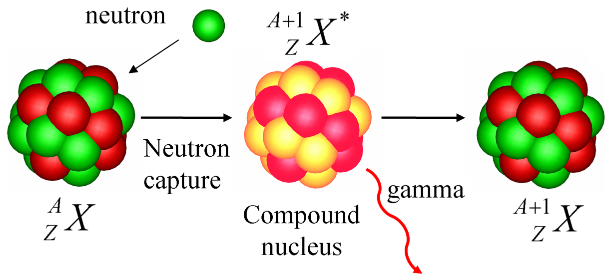


ORIGEN is the key component for all depletion capabilities in SCALE

- **O**ak **R**idge **I**sotope **Gen**eration code in SCALE
- Irradiation and decay simulation code
- Explicit simulation of all pathways from neutron transmutation, fission, and decay
- ORIGEN tracks 2,237 isotopes
    - 176 actinides
    - 1,151 fission products
    - 910 structural activation nuclides







What are ORIGEN reactor libraries ?

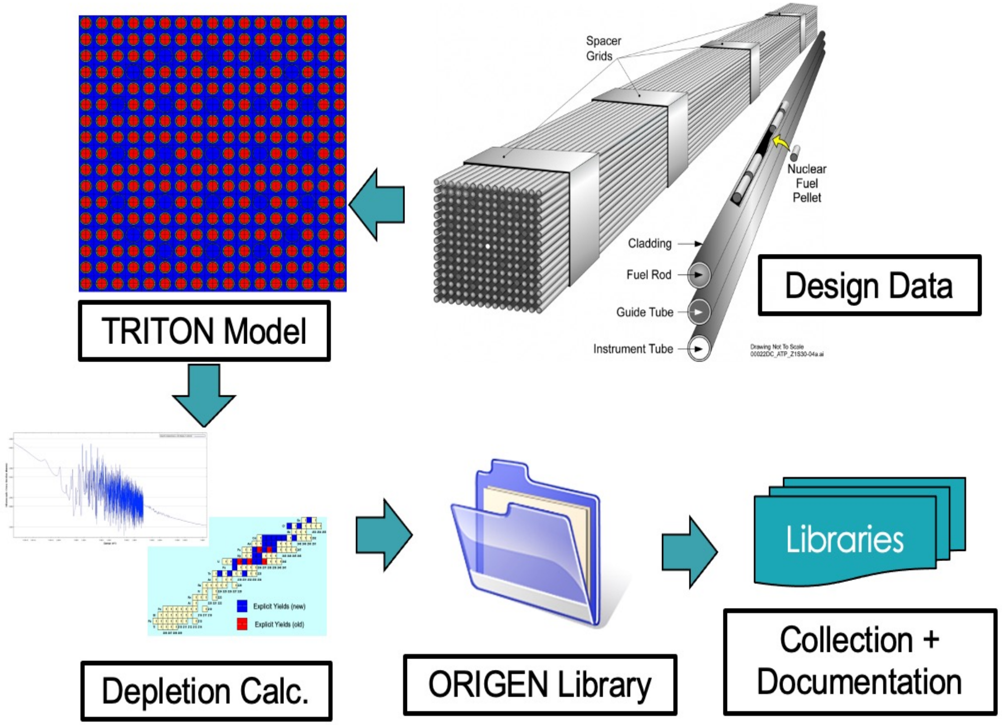
Libraries

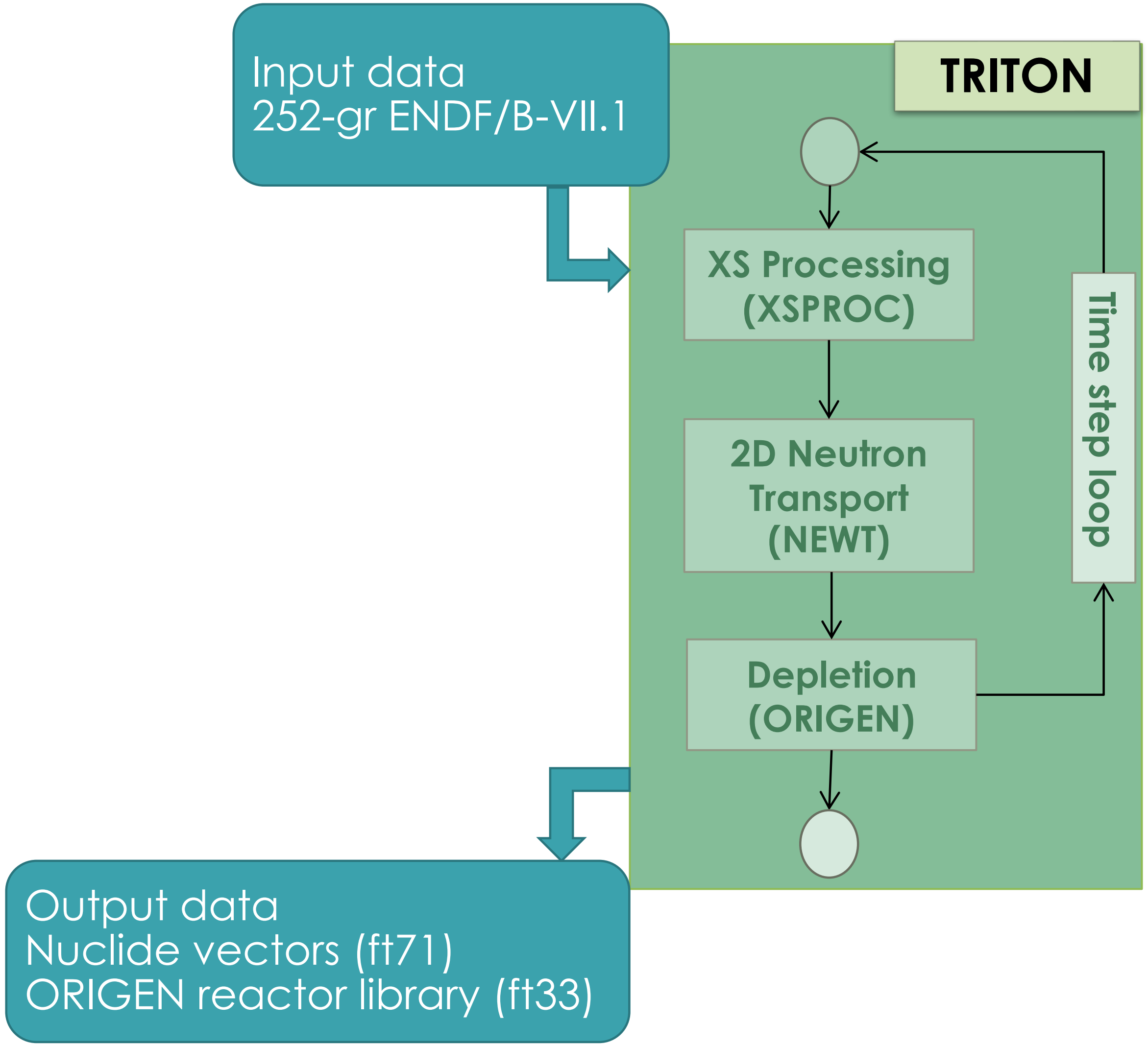
- **ORIGEN Reactor Library** = One set of pre-generated library files with burnup-dependent, 1-group cross sections, and other data ORIGEN needs for depletion simulations (i.e., decay data, fission yields) for a specific reactor type and fuel assembly configuration
  - e.g. PWR W17x17 library
- There is one library file containing burnup-dependent cross sections for a set of discrete values of parameters for the considered assembly design (in libraries released with SCALE)
  - e.g. file corresponding to enrichment 4.0% U-235 and 0.4 g/cm3 coolant density for BWR GE 10X10
- Fuel/reactor specific ORIGEN libraries reside in directory SCALE-6.2\data\arplibs\
- Library information is provided in SCALE-6.2\data**arpdata.txt** file for all reactor libraries
  - Fuel type (name of the reactor library)
  - Number of values for each variable parameter
  - Parameter values
  - Burnup values for each library position
  - Filenames for parameter-dependent libraries

Glossary

- **Fulcrum**
  - cross platform graphical user interface designed to create, edit, validate and visualize SCALE input, output, and data files
- **ORIGAMI** (**ORIG**EN **A**sse**m**bly **I**sotopics) tool for rapid depletion with ORIGEN
  - provides capability to easily perform fast depletion and decay calculations with ORIGEN for LWR fuel assemblies using pre-generated ORIGEN reactor library files
  - is based on the ORIGEN-ARP methodology to enable fast and accurate depletion simulations with ORIGEN, for a given assembly design and user-defined burnup and assembly discrete parameters
- **OPUS**
  - utility to perform post processing and analysis of ORIGEN results contained in ORIGEN nuclide concentrations files (**ft71**), including sorting, ranking, and unit conversion
- **TRITON**
  - depletion sequence [1D, 2D, or 3D neutron transport solver + ORIGEN]
- **Polaris**
  - lattice physics code for simplified and efficient LWR analysis [MOC neutron transport solver + ORIGEN]

Generation of ORIGEN reactor libraries in SCALE 6.2.4





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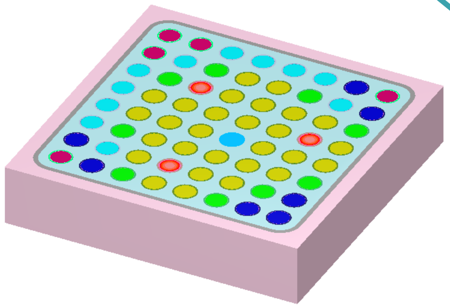
(1) Decay heat calculation with ORIGAMI (ORIGEN)

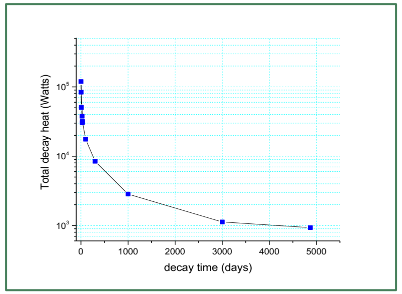
ORIGEN reactor library



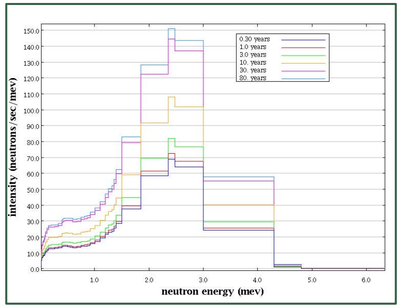
Assembly data
irradiation/decay
history data

ORIGAMI

(ORIGEN)



Nuclide contents
Decay heat
Activities
Sources and spectra



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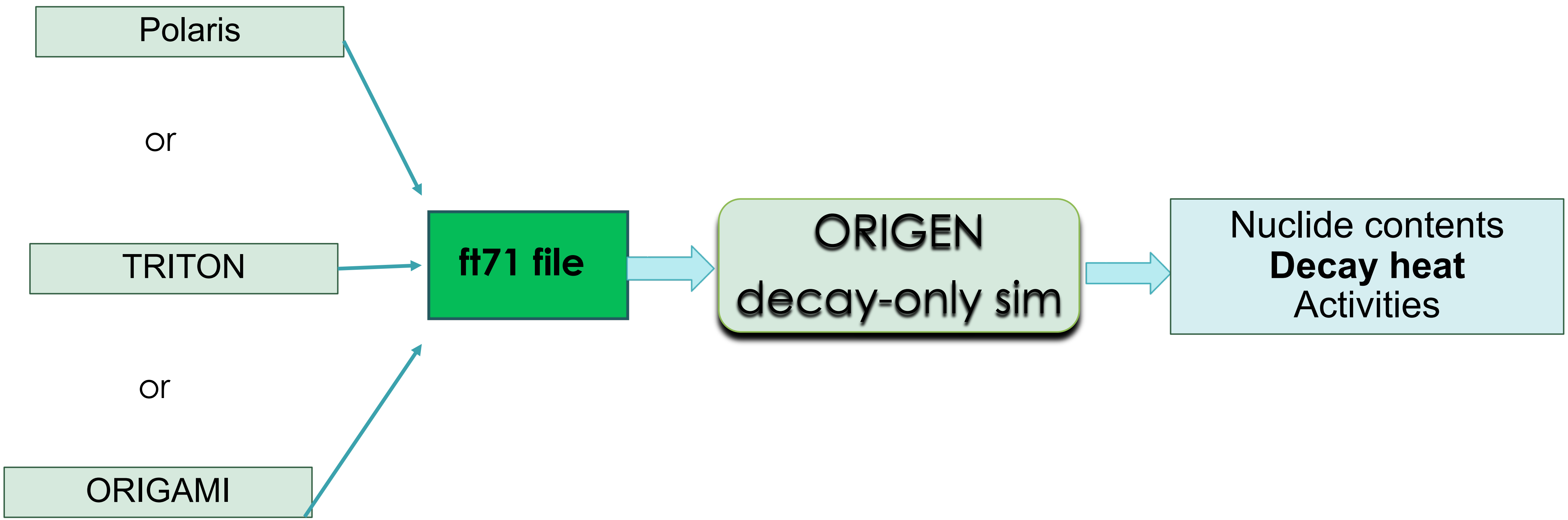
(2) Decay heat calculation with ORIGEN using as input available nuclide vectors from file ft71



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Problem description

- Calculate decay heat for a PWR W17x17 assembly using
  1) ORIGAMI irradiation and decay sim (with SCALE reactor library)
     a) Express input
     b) Detailed input
  2) ORIGEN decay sim with input f71 file available from TRITON (position 53)
  3) TRITON irradiation and decay sim
- For ORIGAMI calculations, use two cases for library (”fuel type”)
  a) generic ORIGEN reactor library w17x17 released with SCALE 6.2.4
  b) custom ORIGEN reactor library generated with TRITON (byproduct of TRITON sim)
- Compare calculated decay heat with measured data for this assembly at cooling time 5823 days
- Measured decay heat: 587.9 W (0E2 assembly ID)
- Input data source: NUREG/CR-6972

Fuel assembly data (NUREG/CR-6972)

- Assembly pitch (cm) 21.50
- Coolant density (g/cm3) 0.72
- Coolant temperature (K) 552
- Average soluble boron level (ppm) 650
- Number of fuel rods 264
- Number of guide tubes 24
- Number of instrument tubes 1
- Rod pitch (cm) 1.26
- Fuel material type UO2
- Enrichment 3.103%
  - U234=0.04%, U236=0.02%
- Spacer material Inconel
- Effective fuel density (g/cm3) 10.27
- Effective fuel temperature (K) 900
- Fuel pellet diameter (cm) 0.8191
- Fuel rod outside diameter (cm) 0.95
- Clad material Zircaloy-4
- Clad thickness (cm) 0.0571
- Average clad temperature (K) 573
- Tube material Zircaloy-4
  - Outer diameter (cm) 1.224
  - Thickness (cm) 0.0406

Fuel assembly data (cont.)

- Assembly burnup (GWd/MTU) 41,628
- Assembly initial U load (kg) 463.60
- Number of irradiation cycles: 4
- Cycle duration (days) 305, 323, 335, 338
- Downtime (days) 47, 49, 47
- EOC burnup (GWd/MTU)

  7,496 20,530 31,838 41,628
- Derived specific power (MW/MTU)

  24.577 40.353 33.755 28.964

- Assembly light element content (kg/MTU)

Al	6.497E-02	B	3.900E-04
C	5.198E-03	Cr	2.621E+00
Cu	1.949E-02	Fe	1.342E+00
Hf	1.524E-02	Mn	2.274E-02
Nb	3.330E-01	Ni	6.822E+00
P	9.750E-04	S	9.750E-04
Si	2.274E-02	Sn	2.209E+00
Ta	3.330E-01	Ti	1.169E-01
Zr	1.497E+02		

Let's work on this together !